ZooKeys 1166: 351–373 (2023)
DOI: 10.3897/zookeys.1166.102854

Research Article

Distribution and diversity of fishes and lampreys in Transylvania (Romania): a complete survey and suggestions for new protected areas

András Attila Nagy[1,2], Nándor Erős[1,3], István Imecs[4], Gábor Bóné[2,5,6], Attila Fülöp[1,7,8], Péter László Pap[1]

1 *Evolutionary Ecology Group, 3B Centre for Systems Biology, Biodiversity and Bioresources, Hungarian Department of Biology and Ecology, Babeş-Bolyai University, Clinicilor street 5–7, RO–400006 Cluj-Napoca, Romania*
2 *Milvus Group Bird and Nature Protection Association, Crinului street 22, RO–540343 Târgu Mureș, Romania*
3 *Institute of Aquatic Ecology, Centre for Ecological Research, Bem square 18/C, H–4026 Debrecen, Hungary*
4 *Department of Freshwater Fish Ecology, Hungarian University of Agricultural and Life Sciences, H–2100 Gödöllő, Hungary*
5 *Department of Evolutionary Zoology and Human Biology, University of Debrecen, Egyetem tér 1, H–4032 Debrecen, Hungary*
6 *Juhász-Nagy Pál Doctoral School, University of Debrecen, Egyetem square 1, H–4032 Debrecen, Hungary*
7 *STAR-UBB Institute of Advanced Studies in Science and Technology, Babeş-Bolyai University, Mihail Kogălniceanu street 1, RO– 400084 Cluj-Napoca, Romania*
8 *ELKH-DE Behavioural Ecology Research Group, Department of Evolutionary Zoology and Human Biology, University of Debrecen, Egyetem square 1, H–4032 Debrecen, Hungary*

Corresponding author: András Attila Nagy (nagyandrasattila@yahoo.com)

OPEN ACCESS

Academic editor: Maria E. Bichuette
Received: 2 March 2023
Accepted: 19 May 2023
Published: 13 June 2023

ZooBank: https://zoobank.org/3940B61E-F5E8-4C13-8750-362CFBDA390E

Citation: Nagy AA, Erős N, Imecs I, Bóné G, Fülöp A, Pap PL (2023) Distribution and diversity of fishes and lampreys in Transylvania (Romania): a complete survey and suggestions for new protected areas. ZooKeys 1166: 351–373. https://doi.org/10.3897/zookeys.1166.102854

Copyright: © András Attila Nagy et al. This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International – CC BY 4.0).

Abstract

Freshwater fishes are in a serious state of decline across the world, making them one of the most threatened groups of vertebrates. The Danube River catchment area in Europe holds the richest freshwater fish community, but our knowledge of the current distribution of these species is limited. Transylvania, the largest region of Romania, is one of the important tributaries of the Danube, from where 77 fish and two lamprey species were recorded until now. Despite this large diversity of freshwater fishes, there is a lack of systematic survey of the fish fauna in this region for the past 50 years. In this study, we present data on the occurrence and distribution of fishes and lampreys collected in Transylvania from 2007 to 2022. This data covers 43% of Romania's surface and includes all major rivers from Transylvania. 65 species of fish and three species of lampreys are recorded, and an additional nine fish species are also reported based on information from competent people. Of the 77 fish and lamprey species recorded 19 (24.7%) are non-native, although their relative abundance was low (5.1%) compared to other similar regions in Europe. The first records of *Eudontomyzon mariae*, *Neogobius melanostomus*, *Piaractus brachypomus*, *Pygocentrus nattereri*, and *Salvelinus alpinus* in Transylvanian rivers are presented, as well as the first record of *Cobitis elongata* outside the Nera River basin (from the Caraș River) and the detection of three new populations of the vulnerable *Umbra krameri*. Data on changes in distribution that have occurred since the last comprehensive survey 50 years ago are also provided and the importance of our results in conservation planning are discussed, including the designation of new protected areas for freshwater bodies and the compilation of the Romanian Red List of fishes.

Key words: Conservation, fish distribution, freshwater ichthyofauna, Natura 2000, non-native species

Introduction

Freshwater fishes make up 50% of all fish species (Fricke et al. 2023) and approximatively 25% of all vertebrates (Pough et al. 1999). They make an important contribution to global biodiversity (Dudgeon et al. 2006; Tedesco et al. 2013), and by providing important ecosystem services, they are essential to the maintenance and functioning of freshwater ecosystems (Miqueleiz et al. 2020). Freshwater fish populations are in serious decline worldwide (Moyle and Leidy 1992; Burkhardt-Holm et al. 2005; Xenopoulos et al. 2005; Freyhof and Brooks 2011), making them one of the most threatened groups of vertebrates (Reid et al. 2013). Nearly half (41.2%) of the European native freshwater fish species assessed by the IUCN Red List are considered threatened (Costa et al. 2021), and similar results have been found by other studies (39% according to Darwall and Freyhof 2015). Consequently, the European Union aims to increase the protected areas of its terrestrial surface, including freshwater bodies, to 30% by 2030, with one third of this area being strictly protected (Miu et al. 2020).

Identification of biodiversity hotspots, areas with high concentrations of individuals, such as those used for reproduction, as well as of endemic species and the invasive species threatening native communities, is critical for actions aiming to reduce biodiversity loss (Myers 1988; Gaston et al. 2002). Therefore, to reach conservation goals, detailed information on the distribution of species is crucial, along with knowledge on their ecology, biogeography, and phylogeography (Margules et al. 2002; Cogălniceanu et al. 2013). For fishes, the conservation status of many species is complicated by frequent changes in nomenclature and the widespread acceptance of the Phylogenetic Species Concept (Economou et al. 2007; Koutsikos et al. 2012). Lastly, among the 25 IUCN threat types affecting European freshwater fish, “Invasive Non-Native/Alien Species/Diseases” is the third largest threat, impacting 33.6% of the species (Costa et al. 2021). Therefore, recent data on the distribution of both native and non-native species is important to have.

The last comprehensive survey of the fish fauna of freshwater habitats in Romania, including Transylvania, dates back to 1964 (Bănărescu 1964). In the recent decades, several surveys have been carried out on major rivers in Transylvania, including the Mureș (Nalbant 1995), Criș (Bănărescu et al. 1997), Someș (Bănărescu et al. 1999), Olt (Bănăduc 1999), and Timiș (Bănăduc et al. 2013). However, surveys of smaller rivers, such as Tur, Bega, Crasna, Barcău, Ier, Lăpuș, Arieș, among others, are still scarce (Harka et al. 1998; Harka and Bănărescu 1999; Wilhelm et al. 2001, 2002; Wilhelm 2007, 2008b). The fish fauna of some protected areas in Transylvania has been recently surveyed (Pricope et al. 2009; Imecs and Nagy 2012; Imecs et al. 2014; Telcean et al. 2014; Năstase and Oţel 2016; Năstase and Tošić 2016; Nagy et al. 2019; Nagy and Imecs 2020), but these areas only account for a small amount of the total protected areas in Transylvania. Few other studies on smaller rivers and lakes have been published (Battes and Pricope 2006; Cocan et al. 2020; Lațiu et al. 2022). Given the current gaps in the distribution, abundance, species identity and occurrence of native and non-native species in the Transylvanian rivers, a comprehensive and large-scale survey is necessary to support the conservation efforts of the highly diverse freshwater fish species in the region. Therefore, our

objective in this study is to provide updated information on the distribution and abundance of all freshwater fish and lamprey species in Transylvanian rivers, considering the recent taxonomic nomenclature.

Materials and methods

Study area

Transylvania is the largest region of Romania, covering an area of 102,226 km^2 (43% of Romania). It is bordered by the Carpathian Mountains in the north, east, and south, and by the Pannonian Plain in the west (see Fig. 1). It encompasses three biogeographical regions: Alpine (29.7%), Continental (55.3%), and Pannonian (15.0%). The majority of the larger rivers in the region originate from the Carpathians and flow towards the west (Pannonian Plain). The Mureș is the longest river of Transylvania, stretching over 766 km (718 km in Romania) with a discharge/outflow of 165 m^3/s at the Romanian-Hungarian border. Other large rivers include the Someș River (Someșul Mic and Someșul Mare form the united Someș), which has a length of 345 km in Romania (Transylvania) and a discharge of 118 m^3/s, the Criș Rivers (Crișul Repede with 148 km, Crișul Negru with 144 km, and Crișul Alb with 238 km), Bega River (244 km), and the Timiș River (359 km). The lowest sampling site from our study is located at 78 m above sea level on the Timiș River, while the highest sampling site is situated at 1356 m above sea level on the Someșul Rece River.

In the past two centuries, river regulations have affected Transylvanian rivers, especially floodplains and marshes. The largest marsh, the Ecsed Moor, situated on the boundary between Romania and Hungary, was drained in the 19th century. Another important lowland floodplain, the Ier River valley, was also drained. Most of this land has been converted into agricultural land. After accession to the European Union in 2007, agriculture intensified significantly, with monocultures taking priority over small parcels of land, which probably have an effect on the fish communities of the rivers. Although there are relatively few large cities in the region, the numerous villages may pose an important source of pollution. The five largest cities in Transylvania are Cluj Napoca (with 286,598 inhabitants), Timișoara (250,849), Brașov (237,589), Oradea (183,105), and Arad (145,078) (2021 population census).

Data collection

Data were collected between 31 March 2007 and 29 October 2022 from a total of 679 sampling sites, including all rivers and major tributaries in Transylvania (Fig. 1). Our survey was focused on rivers, still we occasionally sampled backwaters, ponds, and drainage channels with stagnant water to gather data on species that inhabit these waters and are threatened by habitat loss. Standing waters represent 6% of the total sampling sites. Fishponds and artificial lakes were not surveyed at all. We chose the location of sampling sites to ensure relatively uniform coverage of each river. Although we invested higher sampling efforts in some areas, we attempted to achieve representative coverage of all rivers (Fig. 1). Fishing was carried out with a 12V battery-powered electrofishing device (Samus 725 or Samus 1000), and data collection was performed by wading (Sály et al. 2009). This method consists of moving slowly upstream in the shallow waters

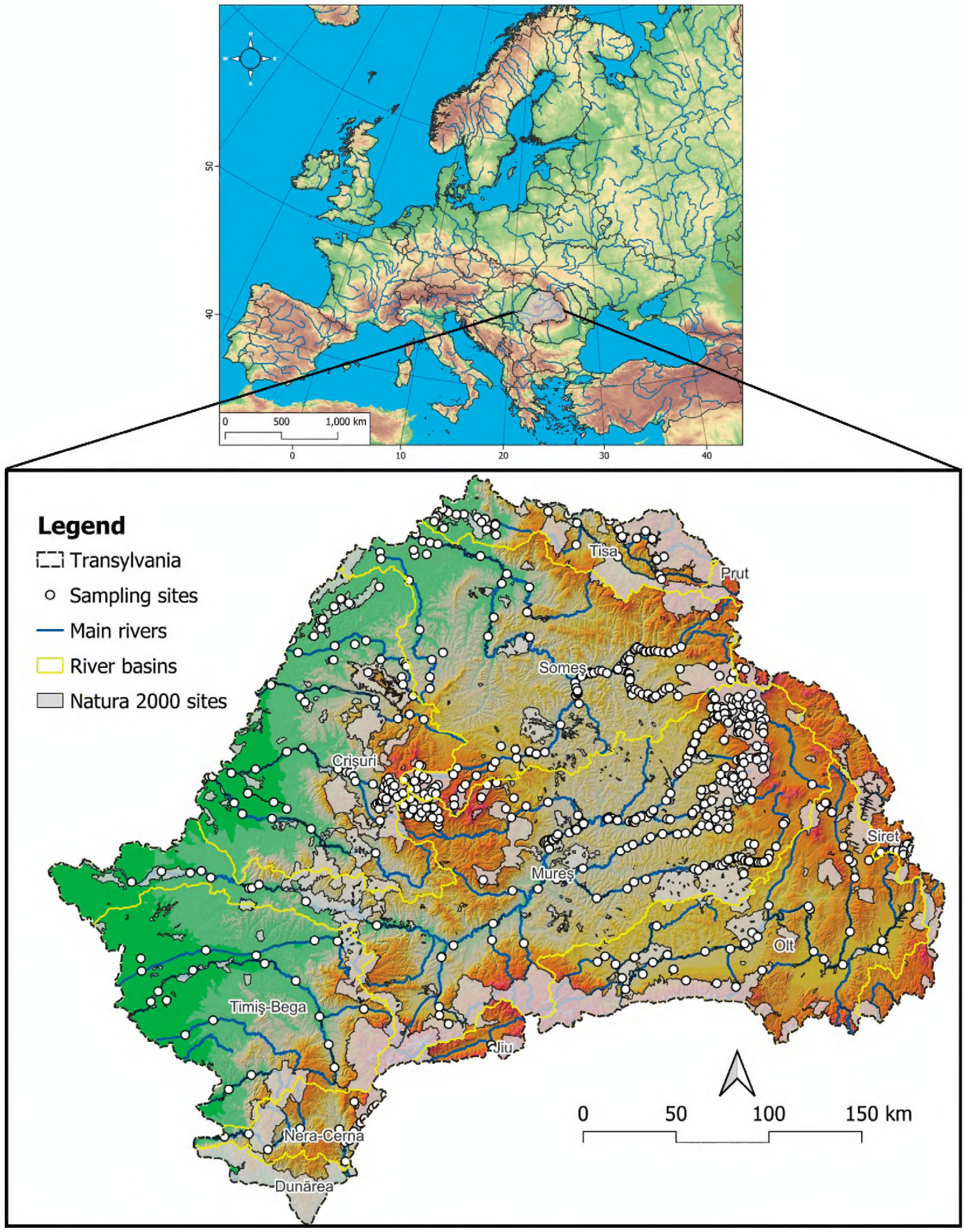

Figure 1. Position of Transylvania, Romania, in Europe, showcasing the main rivers, river basins, Natura 2000 sites (SCIs – Site of Community Interest), and the sampling sites surveyed in the study.

and fishing on one side of the stream in a single pass. Due to current legislative constraints, we were unable to fish from inflatable boats, which is preferable on larger rivers and lakes. Therefore, the fishing method used in our study may underestimate the presence and abundance of species inhabiting deep and/or large (stagnant) water bodies. The length of the sampling sites was set to 150 m in small and medium-sized rivers and 200–300 m in larger rivers, although occasionally, the length of the sampling sites had to be adjusted according to the local field conditions (e.g., shortened if the site was inaccessible). After capture, identification, and taking occasionally morphometric measurements, all individuals

were released in good condition. The raw survey data are stored in the OpenFishMaps database, an open-source database available at https://openfishmaps.ro/, and are available in Suppl. material 1.

We compiled the distribution maps of species using the data from our survey and information provided by anglers, angling associations, fish stocking projects, or the Facebook page "Ichthyology of Romania" (https://www.facebook.com/groups/ichthyologyofromania). From the sources other than our own capture data we only used data that were supported by documentary photographs so that the species could be accurately identified. Information obtained from these sources and additional personal occurrence data for four species (*Cottus gobio*, *Eudontomyzon mariae*, *Sabanejewia romanica*, *Umbra krameri*) is not included in the raw data of distribution (Suppl. material 1) but is indicated separately in the distribution maps (Suppl. material 2). We excluded all hybrids from the dataset, particularly the *Barbus barbus* × *Barbus biharicus*, *Romanogobio uranoscopus* × *Gobio gobio* sensu lato, and the *Barbus petenyi* × *Barbus barbus*. The two *Sabanejewia* species previously belonging to *S. aurata* (*S. balcanica* and *S. bulgarica*) were treated as *Sabanejewia sp*. because the identification of these species in some rivers was uncertain.

Spatial analyses

The survey data stored in the OpenFishMaps database were exported to the R statistical environment (v. 4.2.2; R Core Team 2022) using ESRI shape files. As the database contains data from all regions of Romania, we first selected only the data points within the boundary of Transylvania, then we applied descriptive statistics. For the graphical visualization of the data, to better showcase the distributional patterns of species and different groups of species within Transylvania, we assigned to all sampling sites the cell codes of the overlapping 50 × 50 km ETRS grid, and counted the total number of species, number of native species, number of non-native species, and the number of Natura 2000 species (found in Annex II of the EU's Habitat Directive) for each grid cell. Detailed distribution maps for each species separately are provided in Suppl. material 2. The filtering of the spatial data was performed with the "sf" R package (Pebesma 2018), while data operations were performed with the "dplyr" R package (Wickham et al. 2022). Data visualization was performed using "tmap" R package (Tennekes 2018) and Quantum GIS (version 3.22; QGIS Development Team 2022).

Results

Between 2007 and 2022 we have identified 129,212 individuals belonging to a total of 68 species (65 fish and 3 lamprey species) (Table 1; Suppl. material 1). In addition, the presence of nine other species (*Acipenser ruthenus*, *Ballerus ballerus*, *Coregonus* sp., *Gymnocephalus schraetser*, *Neogobius melanostomus*, *Piaractus brachypomus*, *Pygocentrus nattereri*, *Salvelinus alpinus* and *Sander volgensis*) was confirmed based on information from other verified sources (anglers, angling associations, fish stocking projects, or the Facebook page "Ichthyology of Romania"). Of the 77 identified species (74 fish and 3 lamprey), 19 are non-native. 21 fish and all three lamprey species are protected under the Natura 2000 legislation (Table 1).

Table 1. The complete checklist of freshwater fish and lamprey species of Transylvania (Romania). The taxonomy follows the FishBase online database (Froese and Pauly 2023) with slight modifications.

No.	Scientific name	Recorded until 1969 (Bănărescu 1964, 1969)	New species recorded between 1964 and 2022	Present study	Origin	Natura 2000 protection	Observation
Petromyzontidae							
1	*Eudontomyzon danfordi* Regan, 1911	x		x	native	yes	
2	*Eudontomyzon mariae* (Berg, 1931)			x	native	yes	
3	*Eudontomyzon vladykovi* Oliva & Zanandrea, 1959	x		x	native	yes	
Acipenseridae							
4	*Acipenser gueldenstaedtii* Brandt & Ratzeburg, 1833	x			native	no	
5	*Acipenser ruthenus* Linnaeus, 1758	x		x	native	no	
Anguillidae							
6	*Anguilla anguilla* (Linnaeus, 1758)	x			native	no	
Cobitidae							
7	*Cobitis elongata* Heckel & Kner, 1858	x		x	native	yes	
8	*Cobitis elongatoides* Băcescu & Maier, 1969	x		x	native	yes	
9	*Misgurnus fossilis* (Linnaeus, 1758)	x		x	native	yes	
10	*Sabanejewia* sp. (incuding *S. balcanica* (Karaman, 1922) and *S. bulgarica* (Drensky, 1928))	x Bănărescu (1964) treated these two spp as ssp: *Sabanejewia aurata balcanica and S. a. bulgarica*.		x	native	yes	
11	*Sabanejewia romanica* (Băcescu, 1943)	x		x	native	no	
Nemacheilidae							
12	*Barbatula barbatula* (Linnaeus, 1758)	x		x	native	no	
Cyprinidae							
13	*Barbus barbus* (Linnaeus, 1758)	x		x	native	no	
14	*Barbus balcanicus* Kotlík, Tsigenopoulos, Ráb & Berrebi, 2002	x All species were treated together as *Barbus meridionalis petenyi* by Bănărescu (1964).	x (Kotlík et al. 2002)	x	native	yes	
15	*Barbus biharicus* Antal, László & Kotlík, 2016		x (Antal et al. 2016)	x	native	yes	
16	*Barbus carpathicus* Kotlík, Tsigenopoulos, Ráb & Berrebi, 2002		x (Kotlík et al. 2002)	x	native	yes	
17	*Barbus petenyi* Heckel, 1852			x	native	yes	
18	*Carassius carassius* (Linnaeus, 1758)	x		x	native	no	
19	*Carassius gibelio* (Bloch, 1782)	x		x	non-native	no	
20	*Cyprinus carpio* Linnaeus, 1758	x		x	native	no	
Xenocyprididae							
21	*Ctenopharyngodon idella* (Valenciennes, 1844)		x (Bănărescu 1981)	x	non-native	no	
22	*Hypophthalmichthys molitrix* (Valenciennes, 1844)		x (Bănărescu 1981)	x	non-native	no	
23	*Hypophthalmichthys nobilis* (Richardson, 1845)		x (Bănărescu 1981)	x	non-native	no	
Tincidae							
24	*Tinca tinca* (Linnaeus, 1758)	x		x	native	no	
Acheilognathidae							
25	*Rhodeus amarus* (Bloch, 1782)	x		x	native	yes	
Gobionidae							
26	*Gobio gobio* sensu lato (Linnaeus, 1758)	x		x	native	no	The taxonomic position of stream dwelling gudgeons is still not clearly detailed (see Takács et al. 2021). Nowak et al. (2008) and Takács (2018) recommended the use of this taxonomic concept.

No.	Scientific name	Recorded until 1969 (Bănărescu 1964, 1969)	New species recorded between 1964 and 2022	Present study	Origin	Natura 2000 protection	Observation
27	*Gobio obtusirostris* Valenciennes, 1842	The species was treated as a subspecies of *Gobio gobio* by Bănărescu (1964).	x (Takács et al. 2021)	x	native	no	
28	*Pseudorasbora parva* (Temminck & Schlegel, 1846)		x (Bănărescu 1981)	x	non-native	no	
29	*Romanogobio kesslerii* (Dybowski, 1862)	x		x	native	yes	
30	*Romanogobio uranoscopus* (Agassiz, 1828)	x		x	native	yes	
31	*Romanogobio vladykovi* (Fang, 1943)	x		x	native	yes	
Leuciscidae							
32	*Abramis brama* (Linnaeus, 1758)	x		x	native	no	
33	*Alburnoides bipunctatus* (Bloch, 1782)	x		x	native	no	
34	*Alburnus alburnus* (Linnaeus, 1758)	x		x	native	no	
35	*Ballerus ballerus* (Linnaeus, 1758)	x		x	native	no	
36	*Ballerus sapa* (Pallas, 1814)	x		x	native	no	
37	*Blicca bjoerkna* (Linnaeus, 1758)	x		x	native	no	
38	*Chondrostoma nasus* (Linnaeus, 1758)	x		x	native	no	
39	*Leucaspius delineatus* (Heckel, 1843)	x		x	native	no	
40	*Leuciscus aspius* (Linnaeus, 1758)	x		x	native	yes	
41	*Leuciscus idus* (Linnaeus, 1758)	x		x	native	no	
42	*Leuciscus leuciscus* (Linnaeus, 1758)	x		x	native	no	
43	*Pelecus cultratus* (Linnaeus, 1758)	x			native	yes	
44	*Phoxinus phoxinus* (Linnaeus, 1758)	x		x	native	no	
45	*Rutilus rutilus* (Linnaeus, 1758)	x		x	native	no	
46	*Rutilus virgo* (Heckel, 1852)	x			native	yes	
47	*Scardinius erythrophthalmus* (Linnaeus, 1758)	x		x	native	no	
48	*Squalius cephalus* (Linnaeus, 1758)	x		x	native	no	
49	*Telestes souffia* (Risso, 1827)	x		x	native	yes	
50	*Vimba vimba* (Linnaeus, 1758)	x		x	native	no	
Serrasalmidae							
51	*Piaractus brachypomus* (Cuvier, 1818)			x	non-native	no	
52	*Pygocentrus nattereri* Kner, 1858			x	non-native	no	
Siluridae							
53	*Silurus glanis* Linnaeus, 1758	x		x	native	no	
Ictaluridae							
54	*Ameiurus melas* (Rafinesque, 1820)		x (Wilhelm 1998)	x	non-native	no	
55	*Ameiurus nebulosus* (Leseur, 1819)	x		x	non-native	no	
Esocidae							
56	*Esox lucius* Linnaeus, 1758	x		x	native	no	
Umbridae							
57	*Umbra krameri* Walbaum, 1792		x (Bănărescu 1981)	x	native	yes	
Salmonidae							
58	*Coregonus albula* (Linnaeus, 1758)	x		x *Coregonus.* sp.	non-native	no	
59	*Coregonus lavaretus* (Linnaeus, 1758)	x			non-native	no	
60	*Hucho hucho* (Linnaeus, 1758)	x		x	native	yes	
61	*Oncorhynchus mykiss* (Walbaum, 1792)	x		x	non-native	no	
62	*Salmo trutta* Linnaeus, 1758	x		x	native	no	
63	*Salvelinus alpinus* (Linnaeus, 1758)			x	non-native	no	
64	*Salvelinus fontinalis* (Mitchill, 1814)	x		x	non-native	no	
65	*Thymallus thymallus* (Linnaeus, 1758)	x		x	native	no	

No.	Scientific name	Recorded until 1969 (Bănărescu 1964, 1969)	New species recorded between 1964 and 2022	Present study	Origin	Natura 2000 protection	Observation
Lotidae							
66	*Lota lota* (Linnaeus, 1758)	x		x	native	no	
Odontobutidae							
67	*Perccottus glenii* Dybowski, 1877		x (Covaciu-Marcov et al. 2011)	x	non-native	no	
Gobiidae							
68	*Babka gymnotrachelus* (Kessler, 1857)		x (Cocan et al. 2016)	x	non-native	no	
69	*Neogobius fluviatilis* (Pallas, 1814)		x (Cocan et al. 2014)	x	non-native	no	
70	*Neogobius melanostomus* (Pallas, 1814)			x	non-native	no	
71	*Proterorhinus semilunaris* (Heckel, 1837)	x		x	non-native	no	
Poeciliidae							
72	*Gambusia affinis* (Baird & Girard, 1853)	x			non-native	no	
73	*Poecilia reticulata* Peters, 1859		x (Bănărescu et al. 1997)		non-native	no	
Centrarhidae							
74	*Lepomis gibbosus* (Linnaeus, 1758)	x		x	non-native	no	
Percidae							
75	*Gymnocephalus baloni* Holčic & Hensel, 1974		x (Bănărescu 1981)	x	native	yes	
76	*Gymnocephalus cernua* (Linnaeus, 1758)	x		x	native	no	
77	*Gymnocephalus schraetser* (Linnaeus, 1758)	x		x	native	yes	
78	*Perca fluviatilis* Linnaeus, 1758	x		x	native	no	
79	*Sander lucioperca* (Linnaeus, 1758)	x		x	native	no	
80	*Sander volgensis* (Gmelin, 1789)		x (Telcean and Bănărescu 2002)	x	native	no	
81	*Zingel streber* (Siebold, 1863)	x		x	native	yes	
82	*Zingel zingel* (Linnaeus, 1766)	x		x	native	yes	
Cottidae							
83	*Cottus gobio* Linnaeus, 1758	x		x	native	yes	
84	*Cottus poecilopus* Heckel, 1837	x		x	native	no	

Note: *Petroleuciscus borysthenicus* (Kessler, 1859) was reported from Mureș River basin by Nalbant (1995) but later the author admitted that it was a misidentification (pers. comm. Vasile Oțel, 27 February 2023).

Species with the highest number of occurrences in our sampling sites were the *Squalius cephalus* (present in 56.6% of the sampling sites), *Alburnoides bipunctatus* (51%), *Gobio gobio* sensu lato (39.3%), *Sabanejewia sp.* (including *S. balcanica* and *S. bulgarica*) (37.8%) and the *Rhodeus amarus* (37.7%). Species with the highest number of individuals captured were the *Alburnoides bipunctatus* (16.8% of all individuals), *Squalius cephalus* (10.5%), *Barbus petenyi* (9.8%), *Rhodeus amarus* (7.8%) and the *Alburnus alburnus* (5.6%). The following species had the lowest occurrence: *Ameiurus nebulosus* (captured at one site), *Eudontomyzon vladykovi* (1), *Hypophthalmichthys nobilis* (1), *Babka gymnotrachelus* (2), *Eudontomyzon mariae* (2), *Gymnocephalus baloni* (2), *Hypophthalmichthys molitrix* (2), *Leuciscus idus* (2), *Ctenopharyngodon idella* (3) and *Gymnocephalus cernua* (3), while the 10 least abundant species were the *Ameiurus nebulosus* (one individual), *Eudontomyzon mariae* (4), *Gymnocephalus baloni* (4), *Perccottus glenii* (5), *Hypophthalmichthys nobilis* (5),

Babka gymnotrachelus (7), *Leuciscus idus* (8), *Hucho hucho* (10), *Gymnocephalus cernua* (13) and *Lota lota* (14).

Four fish species caught by fishermen are reported for the first time from Transylvanian natural waters: *Neogobius melanostomus*, *Pygocentrus nattereri*, *Salvelinus alpinus* (all three species caught in 2022) and *Piaractus brachypomus* (caught in 2020 and 2021). *Eudontomyzon mariae* is recorded for the first time from Transylvanian waters, and *Cobitis elongata* is recorded for the first time in Transylvania (in the Caraș River), out of its exclusive occurence in the Nera River basin. We found three new populations of the vulnerable *Umbra krameri*.

The number of fish and lamprey species was the highest (33–40 species; Fig. 2) in the following 50×50 km ETRS grid cells: E525N280 (in the lower Someș basin, 38 species), E540N275 (in the upper Mureș basin, 36) and E515N255 (in the lower Timiș-Bega basin, 36). In contrast, low species numbers (1–8) were observed in E555N270 (Olt and Trotuș River basin, 4 species), E535N255 (9), E530N250 (10) and E530N255 (11) grid cells (upper Jiu, upper Nera-Cerna River, and upper Strei from Mureș basin), albeit these grid cells fall on the boundary of Transylvania and are in mountainous areas (Fig. 2).

The highest number of Natura 2000 species (10–12 Natura 2000 species) were located mainly in lowland areas, but not exclusively: E515N255 (in the lower Timiș-Bega River basin, 12 species), E540N275 (in the upper Mureș River basin, 12 spp), E525N280 (in the lower Someș River basin, 12 spp), E530N285 (Tisa River basin, 11 spp), E530N280 (in the lower Someș River basin, 11 spp), E540N270 (in the upper Mureș River basin, 11 spp), E520N265, E525N265 (in

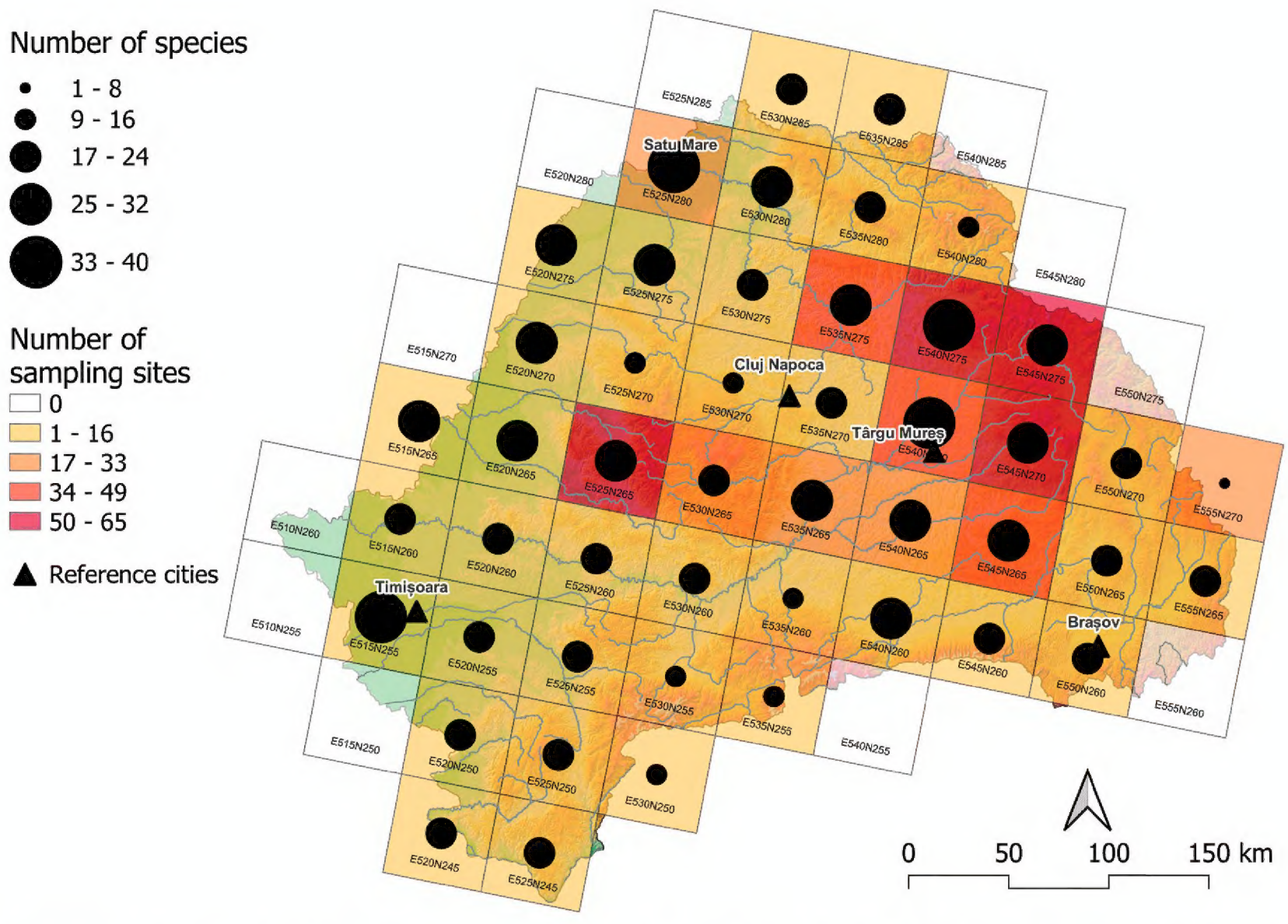

Figure 2. Distribution of total fish and lamprey species, surveyed in 50 × 50 km ETRS grids in Transylvania, Romania. The color of the ETRS grid cells indicates the number of sampling sites, and the size of the dots is proportional with the number of species.

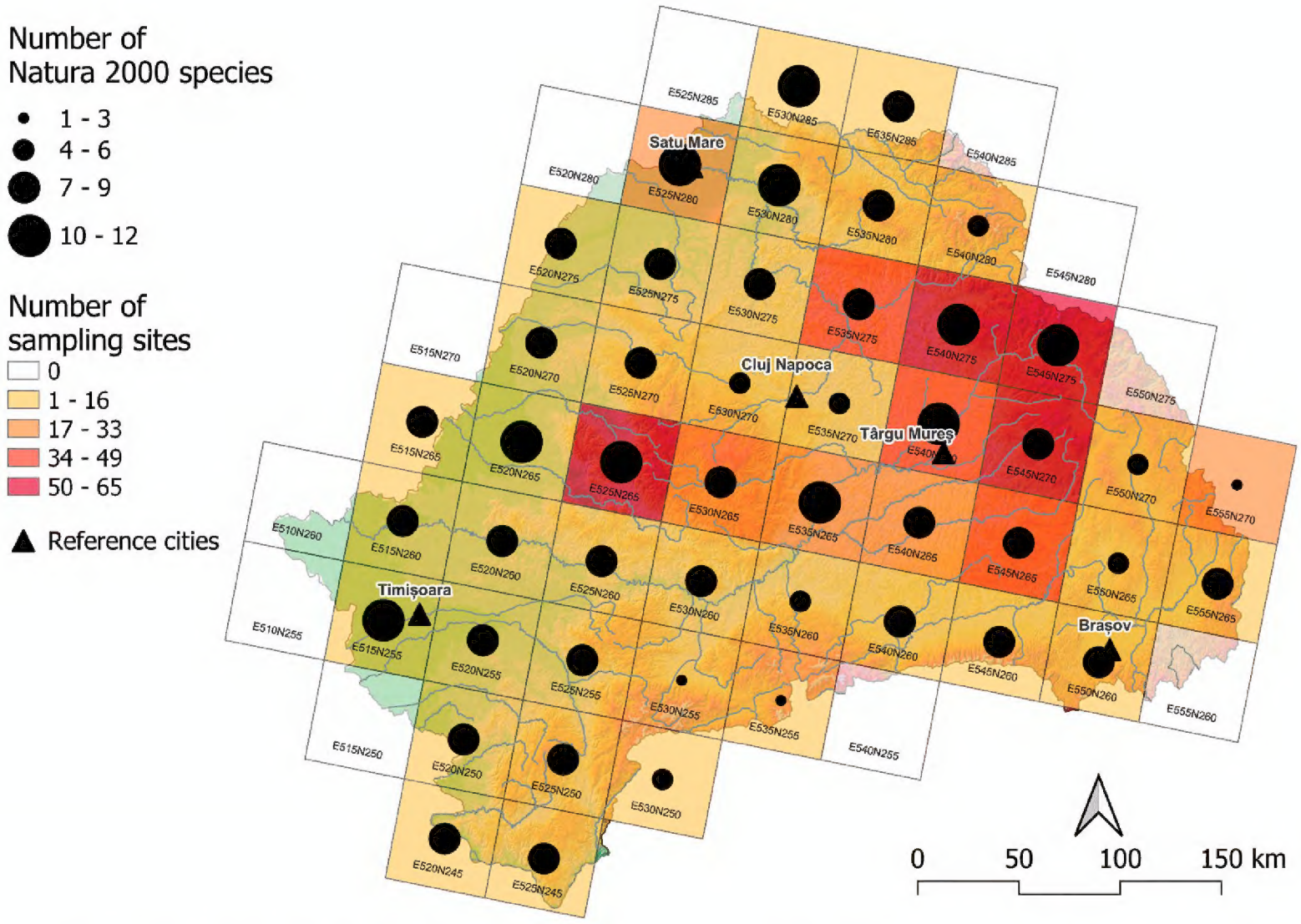

Figure 3. Distribution of Natura 2000 fish and lamprey species, surveyed in 50 × 50 km ETRS grids in Transylvania, Romania. The color of the ETRS grid cells indicates the number of sampling sites, and the size of the dots is proportional with the number of species.

the Crișuri River Basin, 10 spp), E535N265 (middle Mureș River basin, 10 spp) and E545N275 (upper Mureș River basin, 10), (Fig. 3), while the least Natura 2000 fish and lamprey species (1–3 spp) were found in mountain areas: E555N270 (Olt and Trotuș River basin, 1 species), E535N255 (upper Jiu River, 2) and E530N255 (upper Timiș and Mureș River basins, 3 spp).

The highest number of native species was found in lowland areas (E525N280 in the lower Someș River basin, 32 species) and in one grid cell from the hilly-mountainous area (E540N275 upper Mureș River basin, 31 spp) (Fig. 4). Lowest native species number was found in mountainous regions (E555N270, 4 spp, E535N255, 9 spp, and E530N250, 10 spp), albeit these grid cells fall on the boundary of Transylvania (Fig. 4).

The abundance of non-native species was overall low (5.1%). The grid cell with the highest number of non-native species (7) was found in the lowland, in the lower Timiș-Bega River basins (E515N255), while the least invaded areas were found in mountainous areas (Fig. 5).

Discussion

Out of our survey, a total of 77 species of fish and 2 species of lampreys have been recorded in Transylvanian rivers until now (Table 1). Our study reveals the occurrence of 74 fish and three lamprey species in the Transylvanian rivers and ponds. It is important to note that for comparison, we calculated the total species number recorded until now using the same nomenclature as used in this study. Out of the 60 fish and two lamprey species recorded by Bănărescu (1964, 1969) in his comprehensive survey carried out more than 50 years ago, we captured 55 fish and two

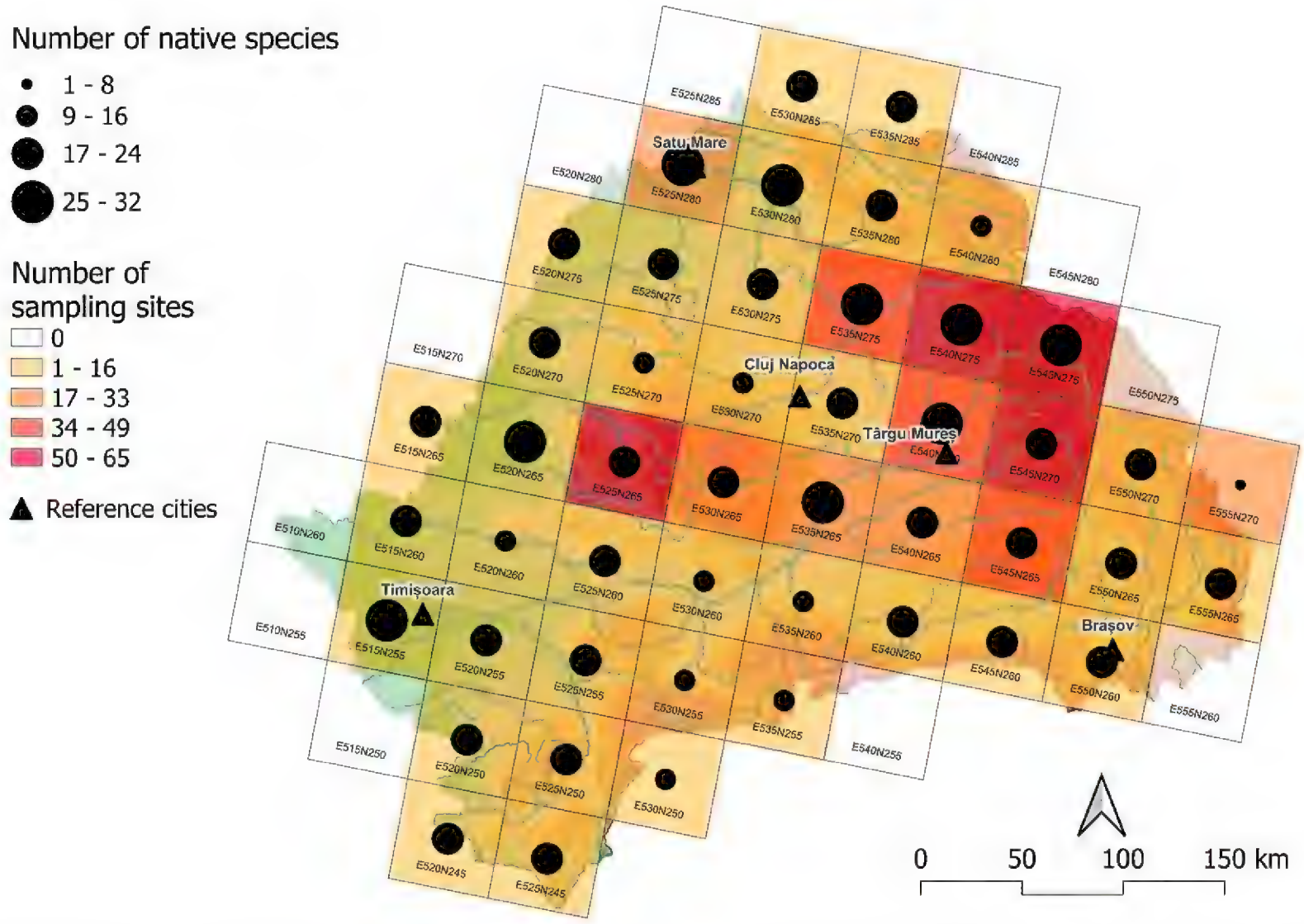

Figure 4. Distribution of native fish and lamprey species, surveyed in 50 × 50 km ETRS grids in Transylvania, Romania. The color of the ETRS grid cells indicates the number of sampling sites, and the size of the dots is proportional with the number of species.

lamprey species, suggesting a slight change in species pool in Transylvanian rivers (Table 1). This change is due to the absence of the following species that were recorded before: *Anguilla anguilla*, *Gambusia affinis holbrooki*, *Pelecus cultratus*, *Rutilus virgo* and one of the two *Coregonus* species (*Coregonus albula* or *Coregonus lavaretus*). These species were recorded sparsely by Bănărescu (1964), and unless there has been a significant increase in their occurrence and abundance between surveys, the likelihood of their recovery is low. Our survey provides an updated overview of the Transylvanian fish fauna. However, the descriptive nature of our study limits our ability to determine the causes of distribution changes. Nonetheless, this study serves as a strong background for future investigations and conservation planning (see below).

Distribution and proportion of native and non-native species

Out of the 77 identified species recorded during our survey, 19 (24.7%) are introduced, while 24 (31.2%) species belong to Natura 2000 species. Of the total of 129,212 captures, 6,553 individuals (5.1%) belong to non-native species, and 46,497 individuals (36%) belong to Natura 2000 species. Overall, the abundance of non-native species in our study region can be considered relatively low. For example, in Hungarian waters, 28.8% of identified species and 18.3% of total captures are non-native (Takács et al. 2017). In various parts of the Mediterranean Basin 25% of fish species are non-native, and in the Iberian Peninsula, where the majority of Europe's threatened fish populations can be found, the proportion of alien species reaches 50% (Leprieur et al. 2008; Clavero et al. 2010; Maceda-Veiga 2013). The distribution of both native and Natura 2000 species throughout Transylvania

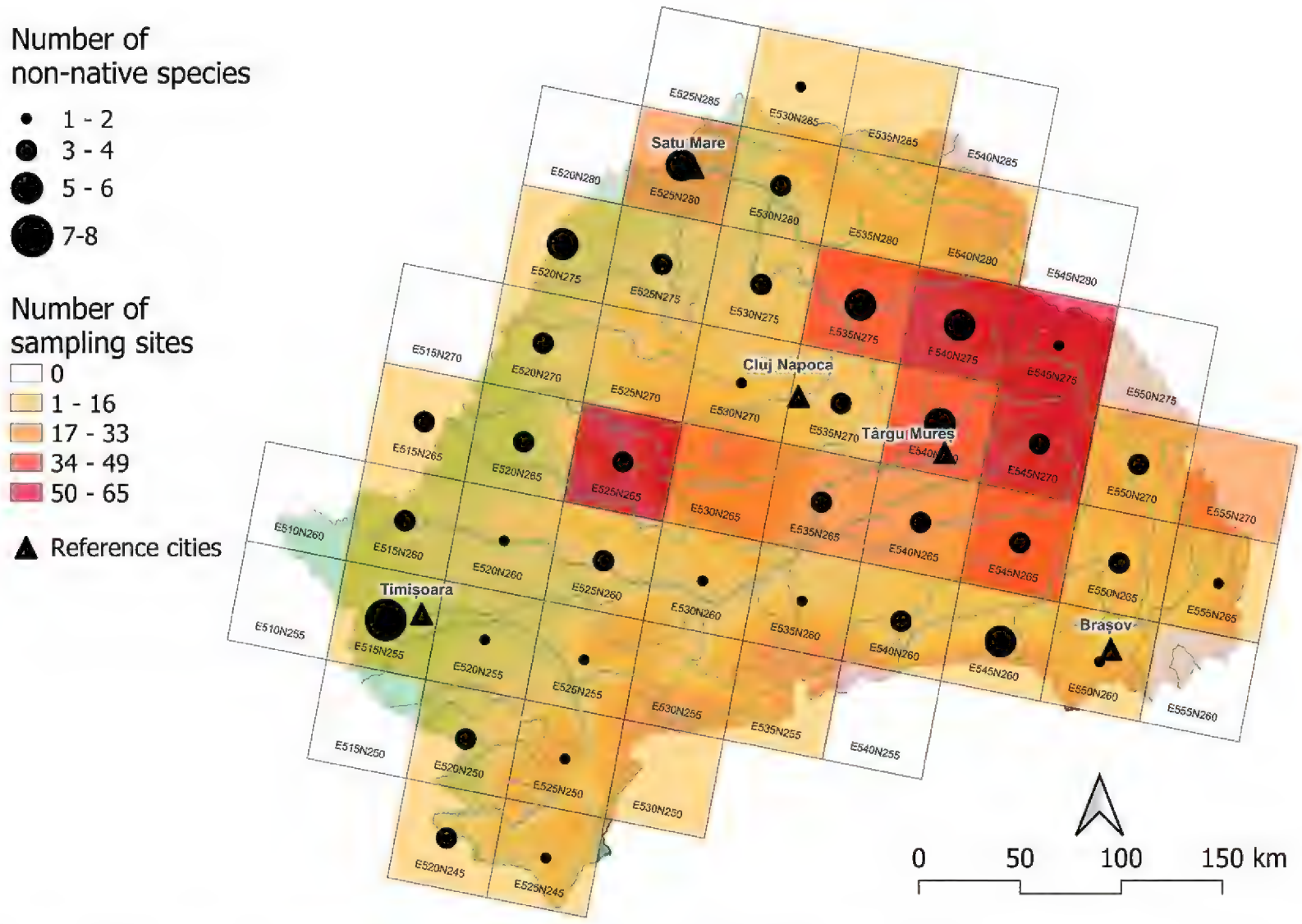

Figure 5. Distribution of non-native fish species, surveyed in 50 × 50 km ETRS grids in Transylvania, Romania. The color of the ETRS grid cells indicates the number of sampling sites, and the size of the dots is proportional with the number of species.

(Figs 3, 4) and the small number and low abundance of non-native species (Fig. 5) demonstrates that the ichthyofauna in the rivers of Transylvania is much closer to a natural state. Although anecdotal evidence suggests that stocking is still low, irresponsibly repopulating river sectors and lakes could potentially exert significant pressure on the river ecosystems from this region. For instance, *Salvelinus alpinus* is reported for the first time in Transylvanian natural waters. A few individuals were caught by fisherman in the Someșul Cald River upstream of the Fântânele reservoir, where it is presumed the species was introduced without authorization.

Comparing our data with those collected during the last comprehensive survey by Bănărescu (1964, 1969), major changes can be observed in the distribution of several species. We present the status of these species below.

Carassius carassius was prevalent in most floodplains in the past (i.e., before 1964) but has now vanished from most of its former habitats (Suppl. material 2: map S17). On the other hand, *Carassius gibelio*, which was present in only a few habitats before 1964, has now expanded its distribution over the main rivers of Transylvania, excluding mountainous habitats (Suppl. material 2: map S18).

Our data indicates that the distribution range of *Zingel zingel* has decreased, as the species has disappeared from the Someșul Mare, Someșul Mic, Crișul Repede, Olt Rivers and the middle part of the Mureș River. We found viable populations of the species in the Someș, Crișul Negru, Crișul Alb, Mureș, and Timiș Rivers, and a very fragile population in the Bega River (Suppl. material 2: map S77). *Zingel streber* has apparently disappeared from the Tur, Someșul Mic, Crasna, Barcău, Arieș, and Bega Rivers (Suppl. material 2: map S76). Our observation supports the findings of Brinker et al. (2018), who also noted a reduction in the historical range of the species in the upper Danube basin due to population fragmentation and habitat loss. It has to be mentioned though that our fishing

method is not proper for evaluating populations of *Zingel* species (Szalóky et al. 2021), therefore the occurrence and abundance of these two *Zingel* species might be underestimated. Our results suggest that the species still maintains significant populations in the Mureș, Crișul Negru, Crișul Alb, and Nera Rivers. The last recorded sighting of the species in the Someș River was in 1964 (Bănărescu 1964), although several studies have been conducted on the ichthyofauna of the Someș River since then (Bănărescu et al. 1999; Năstase and Oţel 2016). Our survey found the species at five sampling sites along the Someș River and at one site along the Someșul Mare River. When studying the ichthyofauna of the Mureș River, Nalbant (1995) only found a few individuals of this species in the fishermen's catch at the Gura Arieșului locality. Our survey found viable populations in the lower and upper-middle part of the Mureș River (the species was present at 24 sampling stations). The species is also present in the Timiș, Olt, and Târnava Rivers, but in much smaller numbers (Suppl. material 2: map S76).

We have observed a drastic reduction in the distribution of *Gymnocephalus schraetser*, as this species was not identified during our surveys, except a few records from other verified sources, although it was found in several rivers (Mureș, Crișul Repede, Crișul Negru, Crișul Alb Rivers) in the 1990s (Nalbant 1995; Bănărescu et al. 1999) and later in the Timiș River (Bănăduc et al. 2013). The species is still present in the Someș, Timiș, and Crișul Negru Rivers (single individuals were observed by local anglers; Suppl. material 2: map S35). Harka and Csipkés (2009) observed a similar drastic contraction of distribution in the Hungarian Bodrog River. Further surveys are needed to map the remaining populations of this species.

Umbra krameri has disappeared from most of its known habitats, particularly from the Ier River valley and from the Carei Plane in north-west Transylvania. In a survey, the species was found only in two out of 13 sites where the species was formerly recorded (Wilhelm 2008a), but three new populations were discovered in the upper valley of the Ier River and one new, but fragile population in the Homorod River of the Crasna River basin. A new population was also found in the Timiș River basin by Covaciu-Marcov et al. (2018) and confirmed by the present study (Suppl. material 2: map S74). These new findings are likely not due to a range expansion of the species in recent decades, but rather because this region of the Romania is understudied.

The presence of *Romanogobio vladykovi* has increased as a result of human activities in the Tisa River basin (Telcean and Bănărescu 2002) and our study confirms former findings (Suppl. material 2: map S59). Another species, *Leuciscus leuciscus*, which had only one confirmed occurrence in the 1990s, has shown significant recovery and was detected in the catchment area of 7 rivers (Suppl. material 2: map S43).

Hucho hucho has returned to the upper Mureș River basin due to stocking (Cengher 2007) after a few decades of absence, but the construction of the Răstolița dam may affect the survival of the species. We found viable population of the species in the Tisa and upper Mureș River basins. (Suppl. material 2: map S36).

Although the method used in our study was moderately suitable for assessing *Cyprinus carpio* populations, our data indicates a massive decline of the species (Suppl. material 2: map S26), especially of the wild form. This change is possibly due to hybridization and river regulation (Freyhof 2010).

Eudontomyzon mariae is reported for the first time in Transylvanian waters and is present in the Olt River basin (Suppl. material 2: map S29). A new, large population of *Cobitis elongata* was found in the Caraș River, in addition to the previously known population in the Nera River basin (Suppl. material 2: map S20).

Three species, *Babka gymnotrachelus*, *Neogobius fluviatilis*, and *Perccottus glenii*, have recently appeared in Transylvania (Covaciu-Marcov et al. 2011; Cocan et al. 2014, 2016). Our observations indicate that these species have expanded their range of distribution. *Babka gymnotrachelus* was found in the Timiș River basin (Suppl. material 2: map S7), *Neogobius fluviatilis* was found in the Someș, Timiș, and Olt River basins (Suppl. material 2: map S46), and *Perccottus glenii* was found in the Tur, Crișul Repede, and Bega Rivers (Suppl. material 2: map S50). The rapid spread of *Perccottus glenii* in Europe and its impact on native fish fauna (Koščo et al. 2003; Reshetnikov 2003, 2013; Reshetnikov and Ficetola 2011; Horvatić et al. 2022) raise concerns, as it is already present in three Transylvanian rivers and its further spread is expected, posing a significant threat to the native fish fauna, especially to the vulnerable *Umbra krameri* (Grabowska et al. 2019).

Pseudorasbora parva, a non-native species, was not present in Transylvania before 1964, but we found it in almost all river basins and at 19.9% of the sampling sites (Suppl. material 2: map S54). *Lepomis gibbosus* was present only in the western part of the region before 1964, but we found it in most of the river basins surveyed (Suppl. material 2: map S39). *Ameiurus nebulosus* was the dominant *Ameiurus* species in Transylvania's waters until the 2000s (Wilhelm 2013), but it has now been almost completely replaced by *Ameiurus melas* (Suppl. material 2: maps S5, S6). Only one specimen of *A. nebulosus* was identified in the Tur River. This replacement of *A. nebulosus* is similar to what has been observed in Hungarian waters (Takács et al. 2017) and confirms the observation of Jaćimović et al. (2019) regarding the invasive potential of this species.

Conservation implications

Many of the Natura 2000 sites from Transylvania have been designated predominantly in mountainous areas to enhance the protection of Natura 2000 fish species, although only a few of these species occur there (as seen in E530N255 and E535N255). However, important river sectors in hilly and lowland areas, which have a high number of Natura 2000 fish and lamprey species, remain unprotected (such as parts of the Crișul Alb River from E520N265, the Bega and Bega Veche River from E515N255, the lower part of the Niraj River from E540N270, and important sectors of the Someș River and the middle and lower part of the Lăpuș River at E530N280). These hilly and lowland river sectors require protection as they are vulnerable to anthropogenic disturbances, particularly due to river regulation. These areas are home to most of the native and Natura 2000 species (Figs 3, 4). Furthermore, the presence of rare or endangered species alone is a sufficient reason to protect an entire aquatic habitat (such as the *Umbra krameri* in the Timișul Mort River or Homorodul Vechi River). Therefore, we propose that in future designation of protected areas, not only the number of Natura 2000 species should be considered (Fig. 3), but also species occurrence maps. This is because, in some cases, the presence of rare or endangered species is a compelling argument for the establishment and

designation of a protected area. Based on our survey, we suggest several river sectors for inclusion in the Natura 2000 network to ensure the protection of the most valuable and diverse river stretches (as listed in Table 2).

Considering that Romania does not currently have an officially adopted Red List for fish and lamprey species, our results can contribute to the creation of such a list. Some species, although not listed as Natura 2000 species, are of prime conservation concern due to drastic reductions in their distribution (e.g., *Carassius carassius*, *Leucaspius delineatus*, *Lota lota*, *Tinca tinca*) or diminished abundance (*Thymallus thymallus*) in recent decades. It is crucial to assess their current conservation status to ensure their long-term survival. Many environmental impact assessments are hindered by a lack of up-to-date data on fish fauna, and often rely on assessments that are not appropriate for studying fish communities. Our data can provide valuable information for these conservation studies.

Table 2. River sections from Transylvania, Romania, proposed for protection and reasoning for designation. The ROSCI codes define the current Natura 2000 sites.

Proposed SCI	Reasoning for designation	Natura 2000 species for which protection is recommended	Description
Timișul Mort River	The largest *Umbra krameri* population from Transylvania, according to our present knowledge	*Umbra krameri*	From Pădureni to Macedonia (the whole sector of the Timișul Mort River and its floodplain that is not included currently in ROSCI0109 and ROSCI0348)
Homorodul Vechi River	The last and only known *Umbra krameri* population from the Crasna River basin	*Umbra krameri*	The whole Homorodul Vechi River and its floodplain (between Cionchești and confluence with the Crasna River)
Lăpuș River	One of the best preserved highland river sector with high fish diversity	*Romanogobio vladykovi*, *Romanogobio uranoscopus*, *Romanogobio kesslerii*, *Rhodeus amarus*, *Barbus carpathicus*, *Cobitis elongatoides*, *Sabanejewia balcanica*	From ROSCI0030 to the confluence with the Săsar River.
Someș River between Dej and Tămaia	High species diversity	*Romanogobio vladykovi*, *Romanogobio uranoscopus*, *Romanogobio kesslerii*, *Rhodeus amarus*, *Barbus carpathicus*, *Cobitis elongatoides*, *Sabanejewia balcanica*, *Zingel streber*	From Dej to Tămaia, excluding the two short sections which are already Natura 2000 SCI (ROSCI0314 and ROSCI0435).
Upper basin of the Barcău River	High species diversity. The only known Transylvanian population of the *Salmo trutta* characterized with the phenotype of missing red spots.	*Eudontomyzon danfordi*, *Romanogobio kesslerii*, *Rhodeus amarus*, *Sabanejewia balcanica*, *Cottus gobio*	Barcău River and its tributaries (Iaz, Valea Mare, Drighiu) from the ROSCI0322 to Marca locality
The middle sector of the Timiș River, between Prisaca and Lugoj	High species diversity	*Romanogobio uranoscopus*, *Romanogobio kesslerii*, *Rhodeus amarus*, *Barbus petenyi*, *Sabanejewia balcanica*, *Cobitis elongatoides*	Between Prisaca and Lugoj
Upper and middle sector of the Bega River	High species diversity. One of the few rivers from Transylvania where *Eudontomyzon vladykovi* still have stronghold populations	*Eudontomyzon vladykovi*, *Leuciscus aspius*, *Romanogobio vladykovi*, *Romanogobio uranoscopus*, *Romanogobio kesslerii*, *Rhodeus amarus*, *Barbus petenyi*, *Sabanejewia balcanica*, *Cobitis elongatoides*, *Misgurnus fossilis*, *Zingel zingel*	Between Luncanii de Jos and Timișoara
Bega Veche River	Natural lowland river habitat	*Misgurnus fossilis*, *Rhodeus amarus*	Between Săcălaz and the Romanian-Serbian national border
Upper Crișul Negru River	High species diversity	*Romanogobio vladykovi*, *Romanogobio uranoscopus*, *Romanogobio kesslerii*, *Rhodeus amarus*, *Barbus biharicus*, *Sabanejewia balcanica*, *Cobitis elongatoides*	Between Ștei and Uilacu de Beiuș
Crișul Alb River	High species diversity	*Romanogobio vladykovi*, *Romanogobio kesslerii*, *Rhodeus amarus*, *Leuciscus aspius*, *Sabanejewia balcanica*, *Sabanejewia bulgarica*, *Cobitis elongatoides*, *Zingel streber*, *Zingel zingel*	Between Ineu and Chișineu Criș.
Mureș River Between Aiud and Mintia	High species diversity	*Romanogobio vladykovi*, *Romanogobio uranoscopus*, *Romanogobio kesslerii*, *Rhodeus amarus*, *Barbus petenyi*, *Sabanejewia balcanica*, *Cobitis elongatoides*, *Zingel streber*	Mureș River between Aiud and Mintia, except ROSCI0419
Niraj River	High species diversity	*Eudontomyzon danfordi*, *Romanogobio vladykovi*, *Romanogobio kesslerii*, *Rhodeus amarus*, *Barbus petenyi*, *Sabanejewia balcanica*, *Cobitis elongatoides*	From Eremitu to the confluence with the Mureș River

Remarks on sampling

The species pool and distribution of some species in the study area is likely greater than what our survey shows due to several reasons. Firstly, we mainly sampled rivers and several species that were recorded in the past or are present in neighboring countries are expected to occur in the area, especially in stagnant or enclosed water bodies. Although we did sample a few backwaters to gather data on species that inhabit stagnant waters and are threatened by habitat loss (e.g., *Carassius carassius*, *Leucaspius delineatus*, *Umbra krameri*), a comprehensive survey of these habitats was not conducted. Additionally, the fish fauna of thermal springs and lakes was excluded from the study, despite of some of these habitats are known to host exotic fish populations (Bănărescu et al. 1997). These waters are important sources and dispersal hotspots for some aquaristic cultivated fish species (Takács et al. 2015; Weiperth et al. 2015; Kordás and Juhász 2020) and may also serve as starting points for invasive species. Further sampling of these water bodies is likely to increase the number of introduced species in the Transylvanian fish fauna. Finally, the absence of certain species from our survey (e.g., *Pelecus cultratus*) and apparent gaps in the distribution of others, such as *Abramis brama*, *Leuciscus aspius* or *Sander lucioperca*, can be attributed to the limitations of our sampling method.

Conclusions

Our study provides the most comprehensive and up-to-date data on the ichthyofauna of Transylvanian rivers in the last 50 years. Compared to the historically recorded 77 species of fish and two species of lampreys, we identified 74 fish and three lamprey species. The discovery of one lamprey and four new fish species for Transylvania (*Eudontomyzon mariae*, *Neogobius melanostomus*, *Piaractus brachypomus*, *Pygocentrus nattereri* and *Salvelinus alpinus*) and new populations of several rare species (*Cobitis elongata*, *Sander volgensis*, *Umbra krameri*) highlights the need for further ichthyological research. There is also a need for a similar systematic assessment of the ichthyofauna of standing waters and ponds. Despite the negative impact of human activities on rivers in recent decades, these water bodies still hold a rich fish community that should be protected through designation of new protected areas as part of the Natura 2000 network. Urgent conservation measures are needed to ensure the long-term survival of non-Natura 2000 fish species, particularly those that have suffered significant range reductions. Anthropogenic pressure on fish populations is increasing, making necessary immediate conservation action in order to protect the diverse Transylvanian freshwater fish and lamprey populations.

Acknowledgements

We are grateful to many colleagues who faithfully helped us during fieldwork: Ferenc Alpár Gothárd, Zsolt Hegyeli, Antal Levente Kapás, Alpár Kelemen, István Sándor Komáromi, Attila Kovács, Zoltán Sallai, Ervin Szegedi, Miklós Zsigmond and many others. Data provided by Andrei Togor greatly complemented our distribution maps. People who contributed with own data are Mihai Caltea, Daniel Cocan, Levente Farkas, Călin Latiu, Adrian Maxim, George Cătălin

Muntean, Tudor Papuc, Marius Poenariu, Romeo Stoicescu. Zoltán Benkő greatly helped us in spatial analyses. Vasile Oțel kindly helped us with critical feedback on Table 1. AAN was supported by the Collegium Talentum Programme of Hungary.

Additional information

Conflict of interest

No conflict of interest was declared.

Ethical statement

No ethical statement was reported.

Funding

No funding was reported.

Author contributions

The study was designed by AAN and PLP. AAN, II collected data from the field investigations, NE, GB and AF analyzed the data. AAN and PLP wrote the manuscript with critical feedback from all co-authors. All authors gave final approval for publication and agreed to be accountable for the aspects of work that they conducted.

Author ORCIDs

Nándor Erős https://orcid.org/0000-0001-8921-482X
Attila Fülöp https://orcid.org/0000-0001-5337-336X
Péter László Pap https://orcid.org/0000-0002-3659-7684

Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

References

Antal L, László B, Kotlík P, Mozsár A, Czeglédi I, Oldal M, Kemenesi G, Jakab F, Nagy SA (2016) Phylogenetic evidence for a new species of *Barbus* in the Danube River basin. Molecular Phylogenetics and Evolution 96: 187–194. https://doi.org/10.1016/j.ympev.2015.11.023

Bănăduc D (1999) Data concerning the human impact on the ichthyofauna of the upper and middle sectors of the Olt River. Transylvanian Review of Systematical and Ecological Research 1: 157–164.

Bănăduc D, Stroilă V, Curtean-Bănăduc A (2013) The fish fauna of the Timiș River (Banat, Romania). Transylvanian Review of Systematical and Ecological Research 15(3): 145–172. https://doi.org/10.2478/trser-2013-0040

Bănărescu P (1964) XIII. Pisces-Osteichthyes, Fauna R.P.R. Editura Academiei RPR, București.

Bănărescu P (1969) XII. Cyclostomata-Chondrichthyes, Fauna R.P.R. Editura Academiei RPR, București.

Bănărescu P (1981) Ihtiofauna bazinului Crișurilor în cadrul general al ihtiofaunei bazinului Dunărean. Nymphaea 8–9: 475–481.

Bănărescu P, Telcean I, Bacalu P, Harka Á, Wilhelm S (1997) The fish fauna of the Criş/Körös river basin. Tiscia monograph series: The Criş/Körös Rivers' Valleys. Szolnok–Szeged–Tîrgu Mureş, 301–325.

Bănărescu P, Telcean I, Nalbant T, Harka Á, Ciobanu M (1999) The fish fauna of the Someș/Szamos river basin. Tiscia monograph series: The Someș/Szamos River Valley. Szolnok–Szeged–Tîrgu Mures, 249–268.

Battes KW, Pricope F (2006) Ihtiofauna din Lacul Știucii. In: Lacul Știucii: Studiu monografic. Editura Casa Cărții de Știință, Cluj-Napoca, 62–71.

Brinker A, Chucholl C, Behrmann-Godel J, Matzinger M, Basen T, Baer J (2018) River damming drives population fragmentation and habitat loss of the threatened Danube streber (*Zingel streber*): Implications for conservation. Aquatic Conservation 28(3): 587–599. https://doi.org/10.1002/aqc.2878

Burkhardt-Holm P, Giger W, Guttinger H, Ochsenbein U, Peter A, Scheurer K, Segner H, Staub E, Suter MJ-F (2005) Where have all the fish gone? Environmental Science and Technology 39(21): 441A–447A. https://doi.org/10.1021/es053375z

Cengher B (2007) The characteristics of the huchen's (*Hucho hucho* Linnaeus, 1758) habitat in Mureș River valley (Mureș County, Transylvania, Romania) and conservation of the species in this sector. Acta Ichtiologica Romanica II: 79–92.

Clavero M, Hermoso V, Levin N, Kark S (2010) Geographical linkages between threats and imperilment in freshwater fish in the Mediterranean Basin. Diversity and Distributions 16(5): 744–754. https://doi.org/10.1111/j.1472-4642.2010.00680.x

Cocan D, Mireşan V, Oţel V, Păpuc T, Laţiu C, Constantinescu R, Răducu C (2014) First record of the Pontian Monkey Goby *Neogobius fluviatilis* (Pallas, 1814) in the Someș river, Transylvania - Romania. Pro Environment 7: 240–246.

Cocan D, Oțel V, Lațiu C, Păpuc T, Mireșan V (2016) A New species of the Gobiidae family in Transylvania waters: Racer Goby (*Babka gymnotrachelus*, Kessler 1857). Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Animal Science and Biotechnologies 73(2): 183–191. https://doi.org/10.15835/buasvmcn-asb:12221

Cocan D, Udrescu B, Muntean G, Constantinescu R, Uiuiu P, Nicula A-S, Houssou AM, Lațiu C, Mireșan V (2020) Fish species distribution and diversity indices from Iara river - Transylvania, Romania. Scientific Papers: Series D, Animal Science-The International Session of Scientific Communications of the Faculty of Animal Science 63: 466–472.

Cogălniceanu D, Rozylowicz L, Székely P, Samoilă C, Stănescu F, Tudor M, Székely D, Iosif R (2013) Diversity and distribution of reptiles in Romania. ZooKeys 341: 49–76. https://doi.org/10.3897/zookeys.341.5502

Costa MJ, Duarte G, Segurado P, Branco P (2021) Major threats to European freshwater fish species. The Science of the Total Environment 797: 149105. https://doi.org/10.1016/j.scitotenv.2021.149105

Covaciu-Marcov S-D, Telcean IC, Ferenţi S (2011) Range extension of *Perccottus glenii* Dybowski, 1877 in Western Romania, a new distribution route in the Danube River Basin? Journal of Applied Ichthyology 27(1): 144–145. https://doi.org/10.1111/j.1439-0426.2010.01597.x

Covaciu-Marcov S-D, Cupșa D, Telcean I-C, Sas-Kovács I, Ferenți S (2018) Two new populations of the European mudminnow, *Umbra krameri* (Actinopterygii: Esociformes: Umbridae), in south-western Romania with the first record in the Banat region. Acta Ichthyologica et Piscatoria 48(3): 251–255. https://doi.org/10.3750/AIEP/02405

Darwall WRT, Freyhof J (2015) Lost fishes, who is counting? The extent of the threat to freshwater fish biodiversity. In: Closs GP, Krkosek M, Olden JDE (Eds) Conservation of Freshwater Fishes. Conservation Biology. Cambridge University Press, 1–36. https://doi.org/10.1017/CBO9781139627085.002

Dudgeon D, Arthington AH, Gessner MO, Kawabata Z-I, Knowler DJ, Lévêque C, Naiman RJ, Prieur-Richard A-H, Soto D, Stiassny MLJ, Sullivan CA (2006) Freshwater biodiversity: Importance, threats, status and conservation challenges. Biological Reviews of the Cambridge Philosophical Society 81: 163–182. https://doi.org/10.1017/S1464793105006950

Economou AN, Giakoumi S, Vardakas L, Barbieri R, Stoumboudi MT, Zogaris S (2007) The freshwater ichthyofauna of Greece - an update based on a hydrographic basin survey. Mediterranean Marine Science 8(1): 91–166. https://doi.org/10.12681/mms.164

Freyhof J (2010) *Cyprinus carpio* (Europe assessment). The IUCN Red List of Threatened Species 2010: e.T6181A12559072. [Accessed on 16 February 2023]

Freyhof J, Brooks EGE (2011) European Red List of freshwater fishes. Publications Office of the European Union, Luxembourg.

Fricke R, Eschmeyer WN, Van der Laan R (2023) Eschmeyer's catalog of fishes online database. https://research.calacademy.org/research/ichthyology/catalog/SpeciesByFamily.asp

Froese R, Pauly D (2023) FishBase. World Wide Web electronic publication. www.fishbase.org [Version 02/2023]

Gaston KJ, Pressey RL, Margules CR (2002) Persistence and vulnerability: Retaining biodiversity in the landscape and in protected areas. Journal of Biosciences 27(4): 361–384. https://doi.org/10.1007/BF02704966

Grabowska J, Błońska D, Kati S, Nagy SA, Kakareko T, Kobak J, Antal L (2019) Competitive interactions for food resources between the invasive Amur sleeper (*Perccottus glenii*) and threatened European mudminnow (*Umbra krameri*). Aquatic Conservation 29(12): 2231–2239. https://doi.org/10.1002/aqc.3219

Harka Á, Bănărescu P (1999) Fish fauna of the Upper Tisa. Tiscia monograph series. The Upper Tisa Valley. Szolnok–Szeged–Tîrgu Mures, 439–454.

Harka Á, Csipkés R (2009) Data to the fish fauna of the river Bodrog. Pisces Hungarici 3: 59–64.

Harka Á, Györe K, Sallai Z, Wilhelm S (1998) A Berettyó halfaunája a forrástól a torkolatig. Halászat 91: 68–74.

Horvatić S, Zanella D, Marčić Z, Mustafić P, Buj I, Onorato L, Ivić L, Karlović R, Ćaleta M (2022) First report of the Chinese sleeper *Perccottus glenii* Dybowski, 1877 in the Drava River, Croatia. BioInvasions Records 11(1): 250–266. https://doi.org/10.3391/bir.2022.11.1.26

Imecs I, Nagy AA (2012) Ihtiofauna râului Iara și a afluenților săi în special cu privire la situl natura 2000 ROSCI0263 Valea Ierii. Revista Muzeului Județean Satu Mare, Studii și Comunicări Științifice 12: 15–21.

Imecs I, Nagy AA, Demeter L, Ujvári KR (2014) The fish fauna of the Ciuc Depression (Harghita County, Transylvania, Romania). Pisces Hungarici 8: 69–76.

Jaćimović M, Lenhardt M, Krpo-Ćetković J, Jarić I, Gačić Z, Hegediš A (2019) Boom-bust like dynamics of invasive black bullhead (*Ameiurus melas*) in Lake Sava (Serbia). Fisheries Management and Ecology 26(2): 153–164. https://doi.org/10.1111/fme.12335

Kordás S, Juhász L (2020) The occurrence of Eastern mosquitofish (*Gambusia holbrooki* Girard, 1859) in the thermal water drain of the Kamilla spa in Balmazújváros. Pisces Hungarici 14: 101–106.

Koščo J, Lusk S, Halačka K, Lusková V (2003) The expansion and occurrence of the Amur sleeper (*Perccottus glenii*) in eastern Slovakia. Folia Zoologica 52: 329–336.

Kotlík P, Tsigenopoulos CS, Ráb P, Berrebi P (2002) Two new *Barbus* species from the Danube River basin, with redescription of *B. petenyi* (Teleostei: Cyprinidae). Folia Zoologica 51: 227–240.

Koutsikos N, Zogaris S, Vardakas L, Tachos V, Kalogianni E, Sanda R, Chatzinikolaou Y, Giakoumi S, Economidis PS, Economou AN (2012) Recent contributions to the distribution of the freshwater ichthyofauna in Greece. Mediterranean Marine Science 13(2): 268–277. https://doi.org/10.12681/mms.308

Lațiu C, Papuc T, Muntean G, Uiuiu P, Constantinescu R, Matei-Lațiu M-C, Nicula A-S, Craioveanu C, Mireșan V, Cocan D (2022) Fish species diversity from Someșul Cald river: 50 years after cascade dam constructions. Frontiers in Environmental Science 10: 1–12. https://doi.org/10.3389/fenvs.2022.918745

Leprieur F, Beauchard O, Blanchet S, Oberdorff T, Brosse S (2008) Fish invasions in the world's river systems: When natural processes are blurred by human activities. PLoS Biology 6: e28. https://doi.org/10.1371/journal.pbio.0060028

Maceda-Veiga A (2013) Towards the conservation of freshwater fish: Iberian rivers as an example of threats and management practices. Reviews in Fish Biology and Fisheries 23(1): 1–22. https://doi.org/10.1007/s11160-012-9275-5

Margules CR, Pressey RL, Williams PH (2002) Representing biodiversity: Data and procedures for identifying priority areas for conservation. Journal of Biosciences 27(4): 309–326. https://doi.org/10.1007/BF02704962

Miqueleiz I, Bohm M, Ariño AH, Miranda R (2020) Assessment gaps and biases in knowledge of conservation status of fishes. Aquatic Conservation 30(2): 225–236. https://doi.org/10.1002/aqc.3282

Miu IV, Rozylowicz L, Popescu VD, Anastasiu P (2020) Identification of areas of very high biodiversity value to achieve the EU Biodiversity Strategy for 2030 key commitments. PeerJ 8: e10067. https://doi.org/10.7717/peerj.10067

Moyle PB, Leidy RA (1992) Loss of biodiversity in aquatic ecosystems: evidence from fish faunas. In: Fiedler PL, Jain SK (Eds) Conservation Biology. Springer US, Boston, MA, 127–169. https://doi.org/10.1007/978-1-4684-6426-9_6

Myers N (1988) Threatened biotas: "hot spots" in tropical forests. The Environmentalist 8(3): 187–208. https://doi.org/10.1007/BF02240252

Nagy AA, Imecs I (2020) Survey on the fish fauna along the Tur River Protected Areas on the Romanian side. Studii și Comunicări, seria Științele Naturii 15: 111–130.

Nagy AA, Imecs I, Bartha L, Pap PL (2019) A Torockói-hegység halfaunája. Acta Scientiarum Transylvanica 25–27: 55–68.

Nalbant T (1995) Fish of the Mureș (Maros) river: systematics and ecology. The Maros/Mureș River Valley. Tiscia Monograph series. Tisza Klub, Szolnok–Szeged–Tîrgu Mures, 225–234.

Năstase A, Oţel V (2016) Researches on the fish fauna in some SCIs Natura 2000 from Romania. Aquaculture, Aquarium, Conservation and Legislation 9: 527–540.

Năstase A, Tošić K (2016) Fish communities of the small rivers of Turda and Tureni Gorges. Studia Universitatis Babes-Bolyai Biologia 61: 69–80.

Nowak M, Popek W, Drąg-Kozak E, Epler P (2008) Morphology of the Common Gudgeon, *Gobio gobio* (L.) sensu Lato, from the Vistula River drainage in the context of recent literature data (Teleostei: Cyprinidae). Fisheries and Aquatic Life 16: 37–48. https://doi.org/10.2478/s10086-008-0003-7

Pebesma E (2018) Simple features for R: Standardized support for spatial vector data. The R Journal 10(1): 439–446. https://doi.org/10.32614/RJ-2018-009

Pough FH, Janis CM, Heiser JB (1999) Vertebrate life. No. QL 605. P68. Prentice Hall, Upper Saddle River, NJ.

Pricope F, Stoica I, Battes KW, Ureche D, Milca P (2009) Ichthyofauna status in the catchment areas of the rivers from the Apuseni Mountains Natural Park. Scientific Study and Research - Biology 17: 86–94.

QGIS Development Team (2022) QGIS Geographic Information System. http://qgis.osgeo.org

R Core Team (2022) R: A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. http://www.R-project.org/

Reid GM, MacBeath TC, Csatádi K (2013) Global challenges in freshwater-fish conservation related to public aquariums and the aquarium industry. International Zoo Yearbook 47(1): 6–45. https://doi.org/10.1111/izy.12020

Reshetnikov AN (2003) The introduced fish, rotan (*Perccottus glenii*), depresses populations of aquatic animals (macroinvertebrates, amphibians, and a fish). Hydrobiologia 510(1–3): 83–90. https://doi.org/10.1023/B:HYDR.0000008634.92659.b4

Reshetnikov AN (2013) Spatio-temporal dynamics of the expansion of rotan *Perccottus glenii* from West-Ukrainian centre of distribution and consequences for European freshwater ecosystems. Aquatic Invasions 8(2): 193–206. https://doi.org/10.3391/ai.2013.8.2.07

Reshetnikov AN, Ficetola GF (2011) Potential range of the invasive fish rotan (*Perccottus glenii*) in the Holarctic. Biological Invasions 13(12): 2967–2980. https://doi.org/10.1007/s10530-011-9982-1

Sály P, Erős T, Takács P, Specziár A, Kiss I, Bíró P (2009) Assemblage level monitoring of stream fishes: The relative efficiency of single-pass vs. double-pass electrofishing. Fisheries Research 99(3): 226–233. https://doi.org/10.1016/j.fishres.2009.06.010

Szalóky Z, Füstös V, Tóth B, Erős T (2021) Environmental drivers of benthic fish assemblages and fish-habitat associations in offshore areas of a very large river. River Research and Applications 37(5): 712–721. https://doi.org/10.1002/rra.3793

Takács P (2018) Megjegyzések a Magyarországon előforduló, *Gobio* genusba tartozó küllők taxonómiai helyzetével és névhasználatával kapcsolatban / Notes on the taxonomic position and naming problems of the Hungarian stream dwelling gudgeons (*Gobio*). Pisces Hungarici 12: 63–66.

Takács P, Maázs G, Vitál Z, Harka Á (2015) Akváriumi halak a Hévíz-lefolyó termálvizében Aquarium fishes in the outflow of the thermal Lake Hévíz. Pisces Hungarici 9: 59–64. https://doi.org/10.13140/RG.2.1.4403.4408

Takács P, Czeglédi I, Ferincz Á, Sály P, Specziár A, Vitál Z, Weiperth A, Erős T (2017) Non-native fish species in Hungarian waters: Historical overview, potential sources and recent trends in their distribution. Hydrobiologia 795(1): 1–22. https://doi.org/10.1007/s10750-017-3147-x

Takács P, Ferincz Á, Imecs I, Kovács B, Nagy AA, Ihász K, Vitál Z, Csoma E (2021) Increased spatial resolution of sampling in the Carpathian basin helps to understand the phylogeny of central European stream-dwelling gudgeons. BMC Zoology 6(1): 3. https://doi.org/10.1186/s40850-021-00069-7

Tedesco PA, Oberdorff T, Cornu JF, Beauchard O, Brosse S, Dürr HH, Grenouillet G, Leprieur F, Tisseuil C, Zaiss R, Hugueny B (2013) A scenario for impacts of water avail-

ability loss due to climate change on riverine fish extinction rates. Journal of Applied Ecology 50(5): 1105–1115. https://doi.org/10.1111/1365-2664.12125

Telcean IC, Bănărescu PM (2002) Modifications of the fish fauna in the upper Tisa River and its southern and eastern tributaries. Tiscia Monograph Series 6: 179–186.

Telcean IC, Cupșa D, Sas-Kovacs I, Cicort-Lucaciu A-Ş, Covaciu-Marcov S-D (2014) Some data upon the fish fauna from Carei Plain natural protected area obtained with herpetological methods. North-Western Journal of Zoology 10: S135–S140.

Tennekes M (2018) tmap: Thematic maps in R. Journal of Statistical Software 84(6): 1–39. https://doi.org/10.18637/jss.v084.i06

Weiperth A, Csányi B, György AI, Szalóky Z, Szekeres J, Tóth B, Puky M (2015) Exotic crayfish, fish and amphibian species in various water bodies in the region of Budapest. Pisces Hungarici 9: 65–70.

Wickham H, François R, Henry L, Müller K (2022) dplyr: A grammar of data manipulation. https://cran.r-project.org/package=dplyr

Wilhelm S (1998) Black Bullhead (*Ictalurus melas* Rafinesque, 1820) (Pisces: Ostariophysi: Bagroidea) a new species of fish recently found in Romanian waters. Travaux du Muséum National d`Histoire Naturelle Grigore Antipa 40: 377–381.

Wilhelm S (2007) A Berettyó és mellékvizei halfaunájának változásai. Pisces Hungarici 1: 106–112. https://doi.org/10.34101/actaagrar/25/3043

Wilhelm S (2008a) A lápi póc. Erdélyi Múzeum Egyesület, Cluj Napoca, 118 pp.

Wilhelm S (2008b) Fauna ihtiologică a Bazinului râului Tur. In: Sike T, Márk-Nagy J (Eds) Flora și Fauna Rezervației Naturale Râul Tur, 91–109.

Wilhelm S (2013) A törpeharcsa. Erdélyi Múzeum Egyesület, Cluj-Napoca, 120 pp.

Wilhelm S, Ardelean G, Sallai Z (2001) Fauna ihtiologică a râului Ier. Satu Mare – Studii şi Comunicări 2–3: 137–146.

Wilhelm S, Harka A, Sallai Z (2002) The prevailing anthropogenic effects on certain smaller northwestern Romanian rivers. Tiscia Monograph Series 6: 187–198.

Xenopoulos MA, Lodge DM, Alcamo J, Marker M, Schulze K, Van Vuuren DP (2005) Scenarios of freshwater fish extinctions from climate change and water withdrawal. Global Change Biology 11(10): 1557–1564. https://doi.org/10.1111/j.1365-2486.2005.001008.x

Supplementary material 1

Raw data of sampling sites, fish and lamprey species and their numbers

Authors: András Attila Nagy, Nándor Erős, István Imecs, Gábor Bóné, Attila Fülöp, Péter László Pap

Data type: occurrences (excel file)

Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.

Link: https://doi.org/10.3897/zookeys.1166.102854.suppl1

Supplementary material 2

Maps S1–S77

Authors: András Attila Nagy, Nándor Erős, István Imecs, Gábor Bóné, Attila Fülöp, Péter László Pap

Data type: occurrences (pdf file)

Explanation note: Distribution maps of fish and lamprey species in Transylvania, Romania.

Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.

Link: https://doi.org/10.3897/zookeys.1166.102854.suppl2